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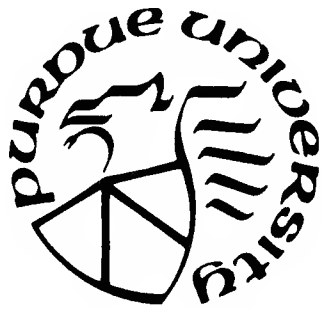
JOINT HIGHWAY RESEARCH PROJECT

FHWA/IN/JHRP-89/15

Executive Summary

LABORATORY INVESTIGATIONS ON LATEX MODIFIED CONCRETE

Sidney Diamond
Qizhong Sheng



PURDUE UNIVERSITY

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Executive Summary

LABORATORY INVESTIGATIONS ON LATEX MODIFIED CONCRETE

Sidney Diamond
Qizhong Sheng

Executive Summary

INVESTIGATIONS IN LATEX MODIFIED BRIDGE DECK OVERLAY CONCRETE

TO: H. L. Michael, Director
Joint Highway Research Project

September 7, 1989

FROM: S. Diamond, Research Associate
Joint Highway Research Project

Project: C-36-19H
File: 5-5-8

Attached is the Executive Summary of the Final Report of the HPR Part II Study titled "Investigations in Latex Modified Bridge Deck Overlay Concrete." The report is entitled "Laboratory Investigations of Latex Modified Concrete" and is authored by Professor Sidney Diamond and Mr. Qizhong Sheng.

The objectives of the study were accomplished. It was found that incorporation of either Class F or Class C fly ash into latex modified concrete produces no harmful consequences, and has the benefit of significantly reducing the chloride permeability of the resulting concrete. It was also found that use of superplasticizer with latex modified concrete may result in major improvements in properties at very modest additional cost, or if the latex content is reduced, at less cost than the present formulation.

A set of recommendations and guidelines for practical application has been included.

This Final Report is forwarded for review and acceptance by all sponsors as fulfilling the objectives of the study. With its approval and subsequent publication the Phase II referenced HPR study will have been completed.

Sincerely,

Sidney Diamond
Research Associate

SD/kr

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EXECUTIVE SUMMARY

LABORATORY INVESTIGATIONS ON LATEX MODIFIED CONCRETE

by

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for

Indiana Department of Transportation

and

Federal Highway Administration
U.S. Department of Transportation

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16. Abstract

Laboratory investigations were carried out (a) to determine the effects of fly ash on the properties of latex modified concrete used for bridge deck overlays, and (b) to explore modified formulations incorporating superplasticizers, silica fume, and combinations of these with reduced latex content (for economy). It was found that incorporating either Class F and Class C fly ashes at 15% and 25% levels produced no deleterious effects, and provided positive benefits in the form of much reduced chloride permeability and the possibility of better bonding to existing concrete. Exploratory investigations of the effects of naphthalene sulfonate superplasticizer on latex modified concretes resulted in highly favorable indications. Major increases were recorded in both compressive and flexural strengths (the latter to over 2,000 psi at 180 days), and the chloride permeability was reduced by a factor of 2. It was found that reducing the latex content in half (for economy) resulted in retaining the compressive strength and chloride permeability improvements but not the increased flexural strength. Incorporating 10% silica fume with the superplasticizer treatment produced no significant increase in strength but reduced chloride permeability to extremely low values. Combining silica fume and superplasticizer with reduced latex content yielded very high compressive strengths (to over 10,000 psi at 28 days) and retained the very low chloride permeability, but degraded the flexural strength significantly. A method was developed for imaging the latex network by scanning electron microscopy. Extensive studies of the pore structures of latex modified cement pastes of various kinds were also carried out.

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EXECUTIVE SUMMARY

The objectives of this project were originally stated as being first, to address the immediate need for hard information on the effects on engineering properties of incorporating fly ash into latex modified concrete (LMC) for bridge deck overlays, and second, to examine the physical structure developed within LMC concrete and based on the information derived, to attempt to develop modified formulations for such use. It was believed that modified formulations including superplasticizers and possibly silica fume used along with the latex might provide either significant cost reductions, superior performance, or both.

The need for this work derived in part from the FHWA policy requiring state transportation agencies to allow the use of fly ash in all concrete at the option of the contractor. This requirement extended to LMC bridge deck overlay concrete as well as to ordinary concrete, despite the fact that almost no published laboratory data existed on the effects of fly ashes on the properties of LMC. The other stimulus for this work was the fact that while LMC had been used successfully in bridge deck overlay applications for over 30 years, there had been no real change in LMC formulation since the late 1950's. In the meantime very considerable advances have been made in conventional concrete resulting in much higher strengths and significantly improved performance. It was thought that reformulations of LMC might provide some of these same improvements.

Special Considerations Pertaining to Latex Modified Concrete

LMC is different from ordinary concrete in a number of important respects. These differences should be pointed out specifically before the results of the investigations are presented.

(1) LMC is extremely expensive concrete. Bid prices naturally vary, but a commonly quoted estimate is $300 per cu. yd., about 5 or 6 times the usual cost of conventional concrete. The cost of the latex itself is about $125 per cu. yd., and LMC is mixed and placed in situ using small volume concrete mobiles rather than conventional mixers.

(2) An unusual feature of LMC is that experience has shown that it must be air-cured after the first day, rather than being continuously wet cured in the normal concrete fashion. This has been done for all latex-bearing formulations in the present work.

(3) Another unusual feature of the field use of LMC in overlays is the limited mixing action obtained with the auger-type mixing units in concrete mobiles. These are not nearly as effective as the pan mixers used in concrete laboratory mixing. Accordingly, caution is advised in possible field application of the results presented here.

Effects of Incorporating Fly Ash in Latex Modified Concretes

With the advice of the INDOT Division of Materials and Tests, four Indiana fly ashes were selected to cover the range of fly ash properties. Three were low-calcium (Class F) fly ashes; one was a widely-used high calcium (Class C) fly ash of superior characteristics. A single Type I cement, widely used in the state, was chosen for all of the experimental concrete. The aggregates used were a calcitic crushed limestone of good quality, and a local natural sand. The latex used was Dow Modifier A.

The standard mix design used by INDOT for LMC (657 lbs. cement/cu.

yd., 30% latex dispersion by weight of cement) was used throughout, except that either 15% or 25% fly ash was substituted for respectively, 12% or 20% by weight of the cement. The concretes were mixed using standard laboratory methods, consolidated by rodding, allowed to hydrate in sealed containers in a fog room for 1 day, and subsequently air-cured at room temperature. Control mixes of (1) normal portland cement concrete and (2) conventional LMC were also prepared using the same cement and aggregates. The water:cement (w:c:) ratio was adjusted as needed to obtain the required slump (5 in + 1 in.)

Effects on Fresh Concrete One of the major benefits of latex use is the water reduction effect of the latex itself. The w:c ratio needed for the particular combination of cement and aggregate used for the plain concrete reference mix was 0.48, slightly more than currently permitted by INDOT specification for Class C structural concrete (0.443). The w:c ratio for the normal LMC with the same ingredients was only 0.29, lower than expected based on the literature; the w:c ratio for LMC is usually reported as being in the range of 0.35 to 0.40. Incorporating fly ash in LMC was found to permit further reduction in w:c ratio, to values between 0.25 and 0.28. The placing and finishing characteristics were essentially unchanged by fly ash incorporation. Working time was about 25 minutes in either case, after which a crust started to form on the fresh concrete.

Effects on Strength One of the original concerns was that fly ash incorporation might significantly reduce strength gain, especially in view of the air curing rather than water curing. This proved not to be the case. For compressive strength, the rate of strength gain for the fly ash bearing concretes was comparable to that of normal LMC. After the first day the compressive strengths of all of the fly ash-bearing concretes (with a single exception) were similar to those of normal LMC

the values being on the order of 2600 psi at 1 day, 7500 psi at 28 days and 8300 psi at 1 year. One fly ash produced slightly lower compressive strengths but even for this fly ash the difference disappeared by 1 year.

Early flexural strengths were slightly reduced by most of the fly ashes, but here also the effects were small and mostly disappeared after about 28 days. Typical flexural strength values were about 600 psi at 1 day, 1400 psi at 28 days and 1800 psi at 1 year.

In neither case was the percentage of fly ash significant; 15% and 25% replacement of the same fly ash produced substantially similar strengths.

Effects on Elastic Modulus The dynamic modulus of elasticity with fly ash was slightly lower than for normal LMC at 1 day, but after a few days the differences disappeared. Typical values were of the order of 5.6×10^6 psi at 1 day, 7.2×10^6 psi at 28 days and 7.4×10^6 at 1 year.

Effects on Bonding To Old Concrete The ability of LMC overlays to bond to underlying old concrete is important, but no standard test procedure exists. A special procedure was developed using a new patented "break-off" tester. The indications obtained were that fly ash actually increased the bond strength.

Effects on Chloride Permeability A critical property for LMC is chloride permeability, as measured in the standard AASHTO electrical test. It was found that fly ash further reduced the already low chloride permeability of LMC. Typical values for the normal LMC were about 550 coulombs at 3 months and 200 coulombs at six months; fly ash reduced these to about 400 coulombs and 120 coulombs, respectively. Generally 25% fly ash provided more of an improvement than 15% fly ash of the same kind.

At late ages (1 year) the chloride permeabilities of both the normal LMC and the fly ash bearing LMC continued to decrease, but the fly ash bearing concretes maintained their margin of superiority. Typical values

at 1 year with fly ash year were only about 80 coulombs, which is classed as "negligible permeability" on the standard AASHTO scale.

Effects on Freezing Resistance Tests of freezing resistance by ASTM C 666 Procedure A showed that fly ash did not degrade the excellent freezing and thawing durability characteristics of latex modified concretes.

Effects on Porosity and Pore Size Distributions Mercury porosimetry trials on LMC cement pastes indicated that the favorable pore structural characteristics of normal LMC were retained with fly ash, and that the pore volume was generally reduced. There were some differences found between the results for the Class C fly ash and the Class F fly ashes.

Effects on Latex Film Characteristics After much experimentation, a method was developed so that details of the three dimensional latex film network could be examined by scanning electron microscopy. It was found that fly ash seemed to make the latex network denser and less porous, and the latex network was directly attached to the fly ash particles.

General Remarks All of the findings above indicate that incorporation of fly ash into LMC either improved, or did not affect the property measured. Mostly the differences were small, but the favorable influence on chloride permeability and perhaps on bond to underlying concrete suggest that fly ash may yield a superior product.

There seem to be no major differences between the effects of the Class C fly ash used and the several Class F ashes; accordingly, it appears that use of any reasonably good quality fly ash should be satisfactory. Replacement levels at least up to 25% seem to be acceptable.

The use of fly ash would require either pre-blending of the fly ash with the cement or addition of another hopper and feed system to the concrete mobile. Neither would be easy to implement in practice. The use of factory-blended fly ash cement (portland-pozzolan cement) would pro-

vide an attractive alternative where available.

Results of Investigations on Reformulation of Latex Modified Concretes

Introduction and Microstructural Results A new scanning electron microscope method used to show the 3-dimensional latex film network in LMC indicated that its characteristics varied with pore structure and other details of the material. Accordingly we considered that admixtures that favorably modified the hydrated cement structure might also have beneficial effects on the latex network as well, leading to substantially improved LMC. Furthermore, we thought that incorporation of superplasticizers might permit reduction of proportion of the very expensive latex component, with a consequent major cost saving.

Only a brief exploration of these possibilities was originally planned, but a six-month extension of the project was obtained to study the effects of superplasticizers and silica fume in some detail.

Various modifications of the normal LMC formulation were examined, including (a) adding naphthalene sulfonate superplasticizer (at two dosage levels), (b) adding both superplasticizer and 10% silica fume (by weight of the cement), (c) adding superplasticizer and reducing the latex content by half, and (d) adding both superplasticizer and silica fume while again reducing the latex content by half.

The properties examined included effects on workability, compressive and flexural strength, modulus of elasticity, and chloride permeability of concrete, and mercury porosimetry of pastes. It was not possible to do a full evaluation of these reformulations, and possible effects on bonding to old concrete, on freezing resistance, and on latex film characteristics were not examined.

Properties of Normal Latex Modified Concrete A new series of control LMC and latex-modifed paste specimens were cast as controls for the new tests. This second control series of LMC had compressive strengths of around 3000 psi at 1 day, 7,000 psi at 28 days, and almost 8,000 psi at 1 year. The corresponding flexural strengths were about 750 psi, 1150 psi, and 1500 psi, respectively. Dynamic elastic modulus values were 5.8 x 10^6 psi, 7.2 x 10^6 psi, and 7.3 x10^6 psi at the same time periods. The chloride permeability values recorded were about 550 coulombs at 3 months and 300 coulombs at 6 months. The total intruded pore volume on mercury porosimetry at 90 days was low, around 0.10 cm^3/g, and it changed little with time. The size distribution of the pores was quite different from that of ordinary cement paste, and did not change much over time.

These properties for "control" LMC are quite satisfactory, and are very much superior to those of the non-latex containing plain portland cement concrete prepared from the same cement and aggregates.

Effects of Incorporating Superplasticizer In these trials the normal latex formulation was unchanged, except that naphthalene sulfonate superplasticizer was added at two dosage levels, 15 oz. and 30 oz./100lbs. cement.

The superplasticizer permitted batching at substantially lower w:c ratios than normal LMC, specifically 0.24 for the 15 oz. treatment and 0.20 for the 30 oz. treatment. There was little or no effect on the placing or finishing characteristics in either case.

It was found that the superplasticizer treatments increased compressive strengths at all ages, with a greater increase showing up for the higher treatment level - 1 day strengths were increased to 3,500 psi, 28 day strengths to almost 8,000 psi, and 180 day strengths (the oldest tested) were 9,500 psi.

Similar strength increases were shown for flexural strength, the

high-dosage levels reaching 800 psi at 1 day, over 1200 psi at 28 days, and over 2,000 psi at 180 days, the latter a quite remarkable value.

The dynamic modulus of elasticity was slightly increased at all ages, but the percentage of increase was small and probably not important.

An important effect was to reduce the chloride permeability, again to a greater extent for the higher dosage level. At this higher dosage level the measured chloride permeabilities were about half those for normal latex concrete (about 250 coulombs at 3 months and 160 coulombs at 6 months).

Yet another important effect was a major reduction in the total pore volume intruded by mercury porosimetry, which was cut in half by the higher dosage superplasticizer treatment.

All of these effects are highly favorable, and point to a great potential improvement in properties of LMC at only a minor marginal additional cost.

Effects of Simultaneously Incorporating Superplasticizer and Silica Fume

Trials again were carried out at two dosage levels of superplasticizer. Both were higher than the dosages used previously to insure dispersion of the silica fume. The lower dosage here was 23 oz. and the higher dosage 38 oz./100lbs. of cement.

It was found that both silica fume mixes were sticky, and that this interfered somewhat with the effectiveness of consolidation by the standard rodding procedure. Accordingly, the test results may not fully reflect potential benefits that may be attained if more effective vibratory consolidation methods were used. The water:cementitious materials ratios achieved in these mixes were identical to the w:c ratios of the mixes with only superplasticizer added, 0.24 and 0.20.

Compressive strengths were found to be in the same general range as achieved with the superplasticizer alone. Flexural strengths were marginally lower, the maximum value reached being only 1550 psi at 180 days.

The dynamic elastic modulus was, surprisingly, rather substantially reduced, being only about 5.5×10^6 psi at 1 day, 6.7×10^6 psi at 28 days, and 6.9×10^6 psi at 6 months.

The major marginal effect of the superplasticizer-silica fume combination over that of superplasticizer alone was a very large additional improvement in chloride permeability, which was reduced to well under 100 coulombs at 3 months and to about 65 coulombs at six months.

However, it was found that the silica fume addition caused a great increase in the pore volume of the paste intruded by mercury porosimetry. The total intruded volume increased from about 0.05 cm^3/g for the heavily superplasticized paste to about 0.15 cm^3/g for the heavily superplasticized paste with silica fume. Most of the extra volume was in very fine pores, with nominal diameters between 100 and 200 Angstroms.

Thus adding silica fume with the superplasticizer has mixed effects. The mechanical properties are surprisingly not improved, and indeed the flexural strength is somewhat reduced. The chloride permeability is brought down to a very low level, a very favorable finding, but the paste porosity is substantially increased, an unfavorable one.

An additional unfavorable consideration is that incorporating silica fume along with superplasticizer in concrete mobile operations would undoubtedly create much greater difficulties than adding superplasticizer alone.

Effects of Reducing the Latex Content While Incorporating Superplasticizer

This combination of treatments was investigated only at a high superplasticizer dosage level (30 oz./100 lbs. cement). Nevertheless, the total materials cost would be significantly reduced since the latex content was cut in half.

The w:c ratio required for a 4 to 6 in. slump increased slightly to 0.22, which is still a very low value. There were no noticeable effects

on placing and finishing. The compressive strengths were actually improved substantially over the corresponding concrete with a full latex dose, reaching almost 5,000 psi at 1 day, over 9,000 psi at 28 days, and over 9,500 psi at six months. Unfortunately, the flexural strengths were somewhat reduced by this modification, to values slightly (but not appreciably) lower than those of normal LMC. The modification also slightly reduced the elastic modulus.

The effect of reducing the latex content on chloride permeability was only marginal. At 3 months the value was a little higher and at 6 months a little lower than that of the superplasticized LMC with a full content of latex, and at both ages was substantially better than normal LMC.

However, one effect of reducing the latex content was to degrade the paste pore structure. Not only was the volume of intruded pores high (about 0.16 cm^3/g), but the size distribution was substantially coarsened.

Reduced latex content superplasticized concretes should present no significant placing difficulties, and should be substantially cheaper than normal LMC. Compressive strengths should be substantially higher, flexural strengths should be unimpaired, and chloride permeabilities should be better. However, pore structures may not be as tight as those of normal LMC. On balance, it appears that such concretes offer the best possibility for future application.

Effects of Reducing the Latex Content While Simultaneously Incorporating Superplasticizer and Silica Fume This treatment combination was also only investigated at the higher superplasticizer dosage level. It should be more expensive than the previous modification because of the cost of silica fume, but still less expensive than normal LMC in materials cost. The mixes were about as sticky as the corresponding full latex dose concretes with silica fume, and other handling characteristic were similar.

The reduction in latex content again caused a slight increase in water demand, to a w:cm ratio of 0.23. Nevertheless, compressive strength was improved, and reached the highest levels obtained in this research; about 3,800 psi at 1 day, over 10,000 psi at 28 days, and over 11,000 psi at 180 days. Flexural strengths were somewhat degraded, and reached only about 1300 psi at 6 months. The elastic modulus was marginally increased.

Somewhat surprisingly, the very low chloride permeability of the full latex dose concrete of this type was retained even when cutting the latex dosage in half, being about 65 coulombs at both 3 and 6 months. The paste pore volume intruded by mercury porosimetry was high (about 18 cm^3/g). This value is similar to that for the other reduced latex content concrete (without silica fume), but in the present case the pore size distribution was not appreciably coarsened.

This projected modification might very well lead to field placement difficulties. It offers technical advantages over the previous modification in higher compressive strength and in a less-degraded pore structure (especially in the matter of size distribution) but the flexural strengths are not attractive, and field placement difficulties may be foreseen unless silica fume containing factory blended cements become available.

Final Remarks Concerning Reformulated Latex Concrete Systems It should again be pointed out that the evaluations of these modified latex concrete systems are incomplete and lacking in important data. The effects on bond strength need to be evaluated, especially for the reduced latex content formulations, and freezing resistance should not be taken for granted. However, the data presented here certainly point to the very strong potential for reformulating latex modified concretes so as to improve strength, durability, and especially, chloride permeability characteristics, and, in some options, to reduce costs as well.

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